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BUILDING ENERGY OPTIMIZATION OF A RESIDENTIAL BUILDING AND DESIGNING A WIND FARM TO SUPPORT THE ENERGY, CONSIDERING ECONOMIC ISSUES

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Abstract- Nowadays considering the industrial activities and the increasing demand for welfare, a rising trend is observed in energy consumption all over the world. One of the most energy consuming components is building category. In the current study, the energy consumption of a residential building in Tehran city is optimized. Then a wind farm is designed to supply the energy demand of a settlement including 100 of the building. The effects of the presence of windows' seams and also implementing different gas in windows gap are studied. Finally, economic justification for constructing wind farm is analyzed using statistical data and field research. Results reveal that implementing double glazed seamless windows including Argon or Krypton show the least energy uses, but considering economic discussion and trade situation, Argon is the optimized option to be used. The calculated required power of the settlement is 3818.8 kW. So, considering a safety factor of 20% a wind farm including six wind turbines with a capacity of 660 kW is designed to supply the demanded electricity.

Keywords: Energy Plus, Building energy optimization, Air conditioning, Wind energy, Economics, Wind farm.

1. INTRODUCTION

In today's advanced world, energy is regarded as a production input with a key role in economic development. Renewable energy resources have recently received much attention due to disadvantages of excessive use of nonrenewable costly fossil fuels such as environmental pollution caused by the production of harmful gases (e.g. carbon monoxide and sulfur oxide) and greenhouse gases (carbon dioxide and methane) [1-3].

According to the statistics on energy consumption in different sectors, released by different organizations, including the World Energy Council, the residential and commercial sectors account for about 30% of total energy consumption in the world. It is noteworthy that a large portion of this energy is used for thermal comfort in buildings, specifically in hot and arid areas [4, 5]. The desire for comfort has been fueled with the improvement of living standards.

Environmental conditions directly affect the mental state, physical conditions, manner and quality of work and generally all aspects of human life. Since people spend much time indoors, it is imperative to create residential comfort. HVAC systems are of great importance in this regard. In the past, not much attention was given to energy consumption in HVAC systems, and thus their energy-efficiency remained an underestimated factor. In recent years, energy consumption by residential and commercial sectors has increased by 20-40% in developed countries. Besides, it is expected that energy consumption follows an upward trend due to population growth and the subsequent increase in energy consumption for thermal comfort in buildings.

According to national statistics in Iran, 35% of the total energy is consumed annually by the residential and commercial sectors, specifically by HVAC systems. These systems typically use electric and/or fossil energy. The HVAC systems account for 15% of total power consumption at peak time and are proportionally involved in environmental pollution because of the power production process [6]. These issues have attracted the attention to energy saving and alternative energy sources. The use of renewable and green energies results in both financial saving and pollution reduction. According to statistics, the residential and commercial sectors produce about 36% of all gases that lead to air pollution [6]. Low energy prices, population and urban growth, poor consumption style and the lack of attention to energy system optimization are among the factors leading to high energy consumption in Iran.

The natural gas consumption in Iran is 30 m^3 per square meter while it is only 5.5 m^3 in developed countries. In other words, energy consumption by the residential sector in Iran is approximately six times higher than in developed countries [7].

The cooling load in buildings accounts for a considerable portion of energy consumption; also, the refrigerants used in common HVAC systems are the main cause of ozone depletion. As a result, the HVAC systems that use green energies as supplementary and/or alternative energy resources have received much attention.

The growing concern on environmental pollution and the need for efficient energy resources highlight the optimization of a HVAC system by reducing energy consumption and pollutant production. The wind energy, as an important energy resource, does not require advanced and costly technologies and thus can be used as a useful energy resource in most parts of the world. The use of green energy is among the most appropriate solutions to achieve economic growth and development in most countries. This natural force can be used for air conditioning, comfort and health and reducing energy consumption in buildings. This study investigated the use of wind energy by explaining the air conditioning mechanism.

In Poland, Prosky (2019) analyzed the air conditioning optimization and found that it is an inclusive term that typically includes thermodynamic process and filtration, air distribution in the room, heating, cooling, humidifying, air canals, and automatic setting subsystems. Moreover, the mathematical description of HVAC is an inclusive issue from a comprehensive and optimization perspective. The author of this article calls this issue "crucial problems" of today's world [8].

In the "Stable Singapore" project, studies by the Department of Environment showed that energy consumption could be reduced by 30% through equipment improvement and facility management; however, more fundamental measures may even result in further energy consumption. According to the results of this project, an increase of 35% in the energy efficiency will be achieved by 2030 relative to 2005 [9].

The feasibility of developing a successful site is investigated from the perspective of financial institutions. The wind altitude measurement is a major parameter for wind turbine designers and manufacturers [10,11]; besides, the wind speed at two-third of the sea level was selected to be included in the wind project development [12].

Window, as a corridor from an artificial to a natural environment, plays a unique role in providing residential comfort. In winter, solar heat can reduce the building's thermal load and total energy consumption. On the other hand, solar heat may also increase the building's cooling load. Consequently, an appropriate adjustment of direct solar radiation to inside and outside environmental conditions can considerably reduce energy consumption and improve residential comfort. Therefore, the assessment of energy saving depends on the positioning of windows and awnings. Investigating thermal and cooling loads, lighting, and annual hours of solar dazzling in different directions indicated no limitations in the surface area of south and north-facing windows of office buildings in Tehran; whereas, an increase in the surface area of windows in other directions results in an increase in annual cooling load and finally energy consumption.

Bagheri et al. (2019) investigated the effect of using different gases for filling double glazed windows and finally recommended the use of the Krypton gas [13].

The type of awning system is an effective factor in building load. Haghani et al. (2017) investigated the effect of implementing the awning on energy-saving and found that its positive impact on the total thermal load in the building. They only investigated the effect of an awning system [14].

Ebrahimi-Moghaddam et al. (2018) investigated the absorption coefficient of different colours on the exterior walls of buildings in Mashhad to determine the most optimal colour in terms of energy consumption throughout the year. They generated a 3D model and meshed the given buildings in GAMBIT and simulated the solar radiation energy with the help of FLUENT. Their results showed that a gray facade can minimize energy consumption in the buildings in all four seasons [15].

Yashino et al. (2018) investigated four office buildings in different cities to evaluate three effective factors of energy consumption in buildings, namely weather conditions, facade materials and residential activities [16]. They changed facade materials to calculate the energy required for residential comfort.

In this study, energy consumption in a residential building in Tehran was optimized by investigating the effects of multi-glazed windows filled with different gases and window seams on energy waste reduction. A wind farm was then designed for a residential complex with 100 buildings explained above. Also, the return on investment (ROI) in wind energy was investigated.

Moreover, the energy consumption in a residential building in Tehran was simulated and investigated with the help of Energy Plus. The energy consumption was optimized by designing specific windows and investigating the effects of wall seams and gas fills. Then, a residential complex with 100 similar buildings was designed, and a wind farm was recommended to supply its electricity needs. An investment payback period of eleven months was estimated for this wind farm.

2. MATERIALS AND METHODS

This study investigated a 7-story building in Tehran. First, the heating and cooling loads of the building were estimated under a one-year scenario. In the first stage, fossil and electricity consumption was measured by assuming a variable-air-volume (VAV) system. In the second stage, the optimal energy consumption in different months was analyzed by using double glazed windows filled with two different gases, namely Argon (Ar) and Krypton (Kr).

In the final stage, a residential complex was assumed with 100 similar buildings and suitable wind turbines (in terms of type and power) for this complex were recommended. Moreover, the investment payback period was estimated using the internal rate of return (*IRR*). The *IRR* is defined as the discount rate at which the net preserve value (*NPV*) of a certain project is zero. The following *NPV* equation was used to calculate *IRR*:

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+IRR)^t} - C_0 \quad (1)$$

C_t : Cash flow in the next t years

C_0 : initial invested cash

IRR: Inflation rate

To calculate *IRR* using this formula, the *NPV* should be assumed zero at the discount rate of *r*. Based on the nature of this equation, IRR cannot be calculated analytically, and trial and error techniques and/or such applications as Microsoft Excel and MATLAB should be used. In this study, IRR was calculated implementing MATLAB.

2.1. Building Energy Consumption Optimization

In the stage of using Energy Plus, the building facade was first designed in Ecotect, and the thermal zones were determined (design file can be imported by all Autodesk applications and converted into an idf file to be used in Energy Plus). It shows total floor space of this building.

It is worth noting that the building design (in terms of architecture and construction) and the raw materials were derived from a real building in West Tehran. In this stage, the climatic characteristics are inputted into the software. To this end, such information as longitude, latitude, height, dry-bulb temperature, and wet-bulb temperature should be collected. Since Tehran's climatic properties exist in the default mode (.epw file), it was automatically set. These measures are presented in Table 1.

The default values of the atmospheric clearness number, the mean reflection from the surface of the Earth and soil conductivity were used. By inputting design parameters into the climactic section of the software, information related to temperature and solar radiation every hour of a month and every month of a year was automatically set. This was a 7-story building with a ground floor parking. Table 2 presents the general information of the building (material, thickness, coordinates, etc.) inputted into the software. It was assumed that the building was surrounded by an open area with no building. Table 2 shows properties of internal and external walls' layers with their ultimate heat transfer rate.

Table 1. Information of design parameters

Parameter	Magnitude
Latitude	535
Longitude	-51.4 °
Elevation	1219.8 m
Summer Design Dry-Bulb	37.7 °C
Summer Coincident WB	23.3 °C
Winter Design DB	-6.7 °C
Winter Coincident WB	-8.8 °C
Atmosphere Clearance Number	1
Average Ground Reflectance	0.2

This research assumed four different types of windows. With-seam and seamless double-glazed windows filled with argon and krypton were examined. Figure 1 presents the building's facade from two different angles.

Table 2. Materials specification I

Material Type	Thickness (m)	Thermal conductivity (w/m.K)	Density (kg/m^3)	Specific heat (J/kg.K)	Thermal resistance (m^2.K/w)
Conc0.1	0.1	1.13	2000	1000	8.85E-02
Floor	0.07	0.41	1200	840	0.1707
Timber-floor	0.03	0.14	650	1200	0.2143
Stone 25 mm	0.02	3.1	2200	790	6.45E-03
Conc-0.1	0.1	0.51	1400	1000	0.1961
Gypsum plastering	0.013	0.4	1000	1000	3.25E-02

Table 3. Materials specification II

Material Name	Roughness	Absorptance Thermal	Absorptance Solar	Absorptance Visible
Conc0.1	Rough	0.9	0.6	0.6
Floor	Rough	0.9	0.73	0.73
Timber-floor	Rough	0.9	0.78	0.78
Asphalt	Rough	0.9	0.85	0.9
Glass-wool	Rough	0.9	0.6	0.6
Break	Rough	0.9	0.7	0.7
Gypsum plastering	Rough	0.9	0.5	0.5
Stone 25 mm	Medium Rough	0.9	0.7	0.7
Colour finish	Smooth	0.9	0.7	0.7
Stucco 25 mm	Smooth	0.9	0.7	0.7
Insulation board 10 mm	Medium Rough	0.9	0.7	0.7
Argon 6 mm	Medium Rough	0	0	0
Krypton 6 mm	Medium Rough	0	0	0
Air 6 mm	Medium Rough	0	0	0

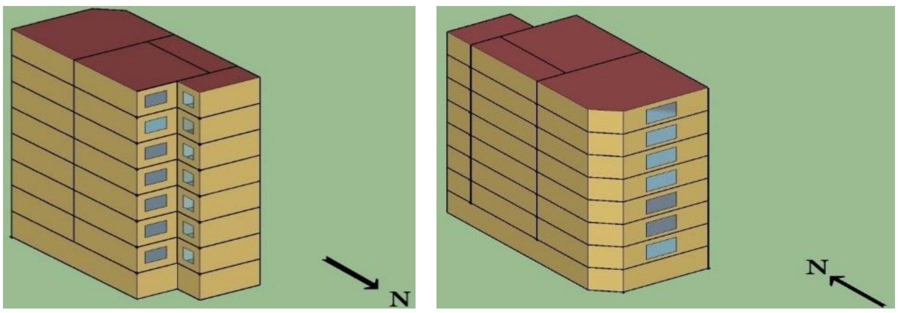

Figure 1. Two external views of the studied building

Efforts were made to optimize cooling and heating energy consumption in a residential complex in the warm and dry climate of Tehran. As mentioned earlier, this study intended to reduce the required energy load for residential comfort by reducing energy consumption as much as possible. To this end, this study considered the reduction of heat transfer. Here in the studied 7-story building, any change in the ceiling and floor materials do not considerably affect total building load. As a result, it was decided to consider changes in window type and seaming.

2.2. Wind Turbine Modeling

According to what was mentioned earlier and estimation of 4 MW wind turbines in Aoun-bin-Ali wind farm, Tabriz, this turbine was recommended for energy consumption optimization, and to estimate the return time of the investment.

Technical specifications of wind turbines in this farm:

- Nominal power: 660 KW
- Rotor diameter: 47 m
- The rotational speed of rotor: 5.28 rounds per minute (rpm)
- Generator's rotational speed: 1515 -1650 rounds per minute (rpm)
- Rotor length: 9.22 m
- Tower height: 40 m
- Gearbox: Solar
- Minimum wind speed for power generation: 4 m/s
- Wind speed for nominal power generation: 15 m/s
- Maximum wind speed for power generation: 25 m/s

Figure 2 shows one of the implemented wind turbines.

Figure 2. One of the wind turbines at Aoun-bin-Ali, Tabriz, Iran

3. RESULTS AND DISCUSSION

The results are presented and discussed here in two main parts, including building energy optimization and modeling the wind farm. Then a feasibility study of wind farm construction is reported.

3.1. Building Energy Optimization

Accordingly, the heating and cooling loads in this building were investigated under four different scenarios. The results from Energy Plus are explained further. Figures 3-6 show diagrams for scenarios I-IV, respectively.

I. The residential building had an Argon-filled double-glazed window with initial seam design.

II. The residential building had a Krypton-filled double-glazed window with initial seam design.

III. The residential building had a seamless double-glazed window filled with Argon.

IV. The residential building had a seamless double-glazed window filled with Krypton.

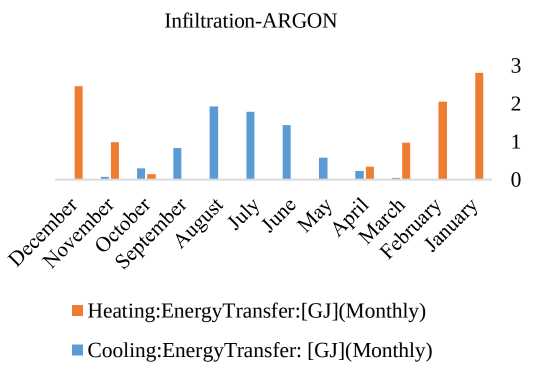

Figure 3. The building's thermal loads in the case of double-glazed window including Argon and with the presence of infiltration

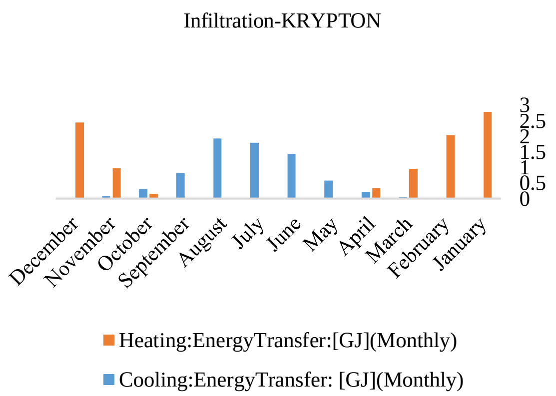

Figure 4. The building's thermal loads in the case of double-glazed window including Krypton and with the presence of infiltration

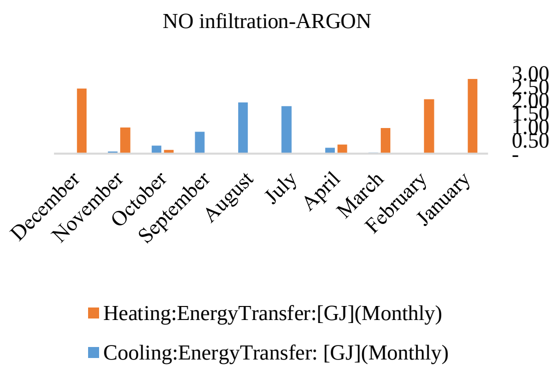

Figure 5. The building's thermal loads in the case of double-glazed window including Argon and with no infiltration

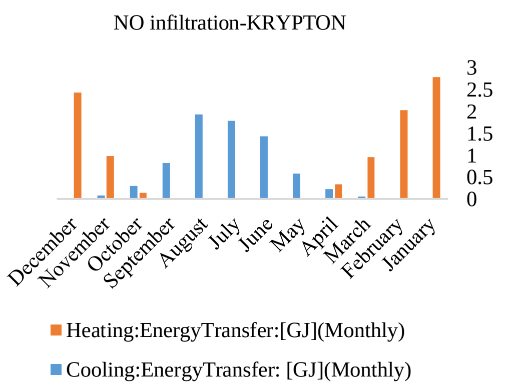

Figure 6. The building's thermal loads in the case of double-glazed window including Krypton and with no infiltration

Figure 7 compares the annual consumption load under different scenarios. A comparison of these four scenarios showed that the seamless double-glazed window filled with krypton was the most optimal scenario in terms of energy consumption. However, the following items were also considered to investigate its economic efficiency: The seaming equipment cost is negligible as compared to the costs of upgrading the quality of gas fills. The krypton-filled windows are rarely found in market because krypton is more expensive than argon.

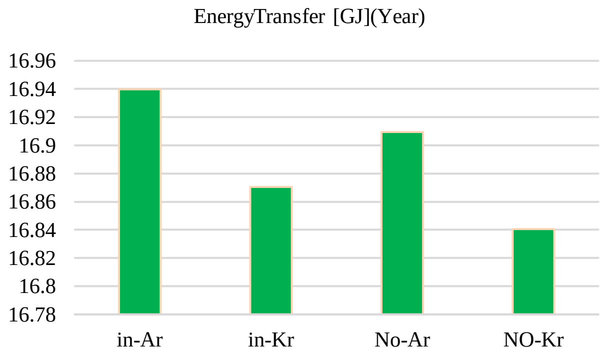

Figure 7. Annually energy consumption of the building for the four studied cases

As a result, the seamless doubleglazed window filed with argon was assumed as the most optimal scenario in terms of cost and energy consumption.

Based on the initial assumptions, the Energy Plus generates specific outputs, some of which are mentioned in the following tables. These results provide a better general insight into the subject.

Table 4 shows the peak load under cooling and heating scenarios in one year. Table 5 shows fuel and water consumption for HVAC per square meter in one year.

Table 4. Power consumption in peak times

Type	Electricity [W]	Natural gas[W]
Peak time	08-AUG-18:59	13-JAN-07:21
Heating load	0	96.63387
Cooling load	81.8759	0

Table 5. The intensity of different resources consumption

Type	Intensity of electricity consumption [kWh/m^2]	Intensity of natural gas consumption [MJ/m^2]	Intensity of water consumption [m^3/m^2]
HVAC	45.79	359.46	0.32

3.2. Modeling the Wind Farm

In this section, the results from Energy Plus are illustrated in Figure 8 with implementing MATLAB to model optimal power consumption for a residential complex consisting of 100 similar buildings. Table 6 presents an estimation of the annual power consumption. Six wind turbines are required to generate 3.5 MW of electricity. Specifications of the turbines are provided before.

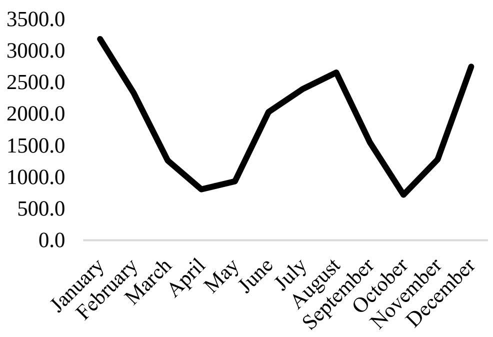

Figure 8. The residential complex Nominal Monthly Power [kW]

Table 6. Different related powers

Average power (kW)	1823.4
Maximum nominal power (kW)	3182.3
Assumed power [n=1.2] (kW)	3818.8

3.3. Feasibility Study Report of Wind Farm Construction

To construct a wind farm for power generation, reliable information on the wind potential in the given area is essential. Iran, with its windy areas, provides this opportunity to exploit wind turbines for power generation. According to the wind atlas prepared based on the information from 60 stations in different regions of Iran, the approximate nominal capacity of all stations amounts 60,000 MW. According to forecasts, the extractable wind power in Iran is 18,000 MW, which requires several studies on the potential and economic feasibility of wind farm construction.

The final indices for a complete comparison of different components in the assessment of wind farms are as follows:

- Costs and revenues of the project
- Investment payback period
- Electricity price and internal rate of return

Considering the need for a sustainable development plan for the expansion of the electricity supply system, the social costs and benefits of each generator should be considered. As a result, only the cost of disposal of environmental pollutants and purification of toxic gases emitted from fossil power plants should be included in the calculations.

These costs include the effects of environmental pollutants in both short and long terms such as the generation of SOx, NOx, COx, hydrocarbons and other toxic gases, soil and water pollution, acid rain and greenhouse gases.

In 2017, the costs of 1 MW and 2.5 MW wind turbines with essential equipment were 285 and 675 thousand dollars, respectively. It is noteworthy that the initial approval of the Ministry of Industry, Mine, and Commerce is needed as the first stage. Besides, technical approvals should be obtained from the respective organizations.

The land required for construction of a 2.5 MW wind farm is one hectare. As a rule for wind farm side-spacing, the turbines should be about three rotor diameters away from each other. With respect to front-spacing, turbines should be about five rotor diameters away from each other along the dominant wind direction.

Table 7 shows the required investment and generation capacity along with other comprehensive information such as the land area and some economic indices. It is worth noting that the mentioned magnitudes and statistics are approximate values.

Table 7. Required investment and generation capacity

Explanation	Magnitude	Unit
Total required investment	1.35	Million dollar
Annual production capacity	4	MW
Ground area	2-3	Hectare
Internal efficiency	20-30	%

According to IRR Equation, and based on an inflation rate of about 20% and utility price in 2019 in Iran, the return of investment reduced to 10-15% with an investment payback period of 10-12 years. Calculations were performed in MATLAB.

To calculate IRR using this formula, the NPV should be assumed zero at a discount rate of r. Based on the nature of this equation, IRR cannot be calculated analytically, and trial and error techniques or such applications as Microsoft Excel and MATLAB should be used. There is no difference between investment and non-investment when the NPV is zero. In other words, when the NPV is zero, the total cost and total revenue are equal because there is no net loss or gain. As a result, this project will have "broken even" after 10-12 months and then start delivering profit. Also, environmental advantages should not be ignored.

4. VALIDATION

To validate the research results, the total energy consumption in the building was calculated in TRNSYS, and the results are provided in Figure 9. It is observable that both of results are very similar and it is a validation point for the current research.

5. CONCLUSION

A building with seamless double-glazed windows filled with Krypton was found to be the most optimal scenario in terms of energy consumption and cost reduction. According to the results, the third scenario was selected as the most optimal scenario. The results from the analysis of a residential complex with 100 buildings indicated that the required electricity power in Tehran's climates could be supplied by constructing a 4 MW wind farm. Moreover, the investment payback period of a wind farm is about 11 months under normal conditions with no economic turbulence or natural disaster.

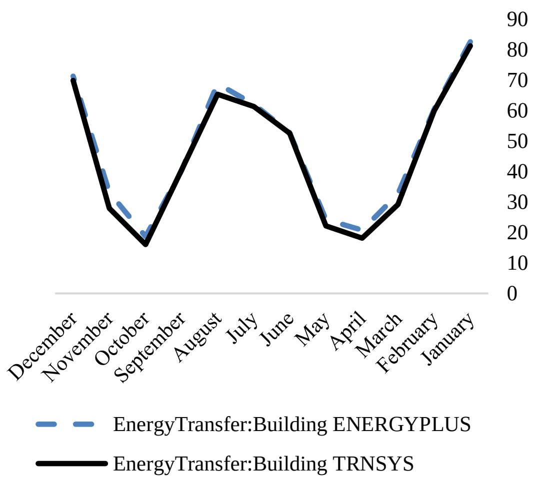

Figure 9. Validation of the Energy Plus results with those of Transys

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